Bioacoustic Absorption Spectroscopy (ASIAEX)

Dr. Orest Diachok
Acoustics Division, Code 7120
Naval Research Laboratory
Washington, D.C., 20375
telephone: 202 404 4650 fax: 202 404 7813 e-mail: orest@wave.nrl.navy.mil

Award Number: N0001498WX30132

Thrust Category: Shallow-Water Acoustics

LONG TERM GOAL

Demonstrate the potential of bioacoustic absorption spectroscopy for tomographic mapping of the bioacoustic parameters of fish with swim bladders in shallow water in the context of the ONR ASIAEX Program.

OBJECTIVES

Develop a propagation model that accounts for the effects of bioacoustic absorptivity on transmission loss in shallow water at frequencies between 0.2 and 10.0 kHz. Develop a bioacoustic model that accounts for the resonance frequencies of absorption lines, which are due to dispersed pelagic fish, and schools of pelagic fish with swim bladders. Demonstrate consistency between absorptivity and echo sounder based estimates of number densities.

APPROACH

Design, construct and test an ultra broadband (0.2 – 10 kHz), light weight, long term, autonomous sources and receivers, that will permit long term monitoring of bioacoustic parameters. Conduct a bioacoustic absorptivity experiment in co-operation with fisheries biologists. This experiment will be designed to investigate the "signature" of the Japanese anchovy, and other fish, which inhabit the seas off China and Japan.

Develop a transmission loss model that includes multiple bioacoustic absorbing layers with realistic shapes. Simulate effects of multiple absorbing layers on transmission loss vs. time and frequency. Apply model to new and previously published bioacoustic absorptivity measurements, derive bioacoustic parameters of anchovies and other fish, and demonstrate consistency with trawling data.

Invert bioacoustic parameters of anchovies from previously reported back-scattering data, which were made in concert with concurrent trawls in the seas off California, by matching theoretical computations with data. Demonstrate consistency between absorptivity and back-scattering based derivations of bioacoustic parameters.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2000**	2. REPORT TYPE	3. DATES COVERED **00-00-2000 to 00-00-2000**
4. TITLE AND SUBTITLE **Bioacoustic Absorption Spectroscopy (ASIAEX)**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Acoustics Division, Code 7120,Naval Research Laboratory,,Washington,,DC,20375**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

I completed my conceptual design, and oversaw the engineering specification and initial testing of a unique, autonomous, light weight, ultra-broadband CW source, which is required for bioacoustic absorptivity experiments. This source is being constructed by Massa Products Corporation for the Naval Research Laboratory, under contract to ONR. It will transmit sequences of 1 to 10 second long, CW tones between 0.2 to 10 kHz with a nominal source level of 170 dB re 1 μPa at 1 m for 24 hours. This source will weigh less than 220 ponds, including batteries, and excluding the anchor and float. The sampling strategy follows: every 0.05 kHz for $0.2 < f < 1$ kHz; every 0.1 kHz for $1 < f < 3$ kHz; and every 0.2 kHz for $3 < f < 10$ kHz. This sampling strategy was designed to permit accurate measurements of the ensemble Q's of absorption lines due to adult and juvenile year classes. Engineering tests are scheduled for January, 2001, which is about 6 months later than originally scheduled. The delay was caused by contractual complications.

In June, 2000 I visited the Sekai National Fisheries Research Institute (SNFRI) in Nagasaki, Japan, and initiated discussions with SNFRI scientists about a collaborative experiment. My likely collaborator, Dr. Seiji Ohshimo, his supervisor, Dr. Asano, and the Director of SNFRI expressed strong interest in the proposed collaborative effort. Dr. Masahiko Furusawa of the University of Tokyo (Fisheries), Japan's leading authority on fisheries acoustics, participated in these discussions.

At present the dominant species of fish in the seas off China and Japan is the Japanese anchovy. This fish resides in the East China Sea and the Yellow Sea on the continental shelf off China (far from the *ASIAEX* site) during summer, and in the East China Sea approximately midway between China and Japan (in the vicinity of the *ASIAEX* site) during winter. This species also occurs in high concentrations on the continental shelf in the Tsushima (Korea) Strait in summer. SNFRI conducts surveys of anchovies every June and July on its side of the "fisheries EEZ" in the East China Sea, the Tsushima Strait, and the Sea of Japan.

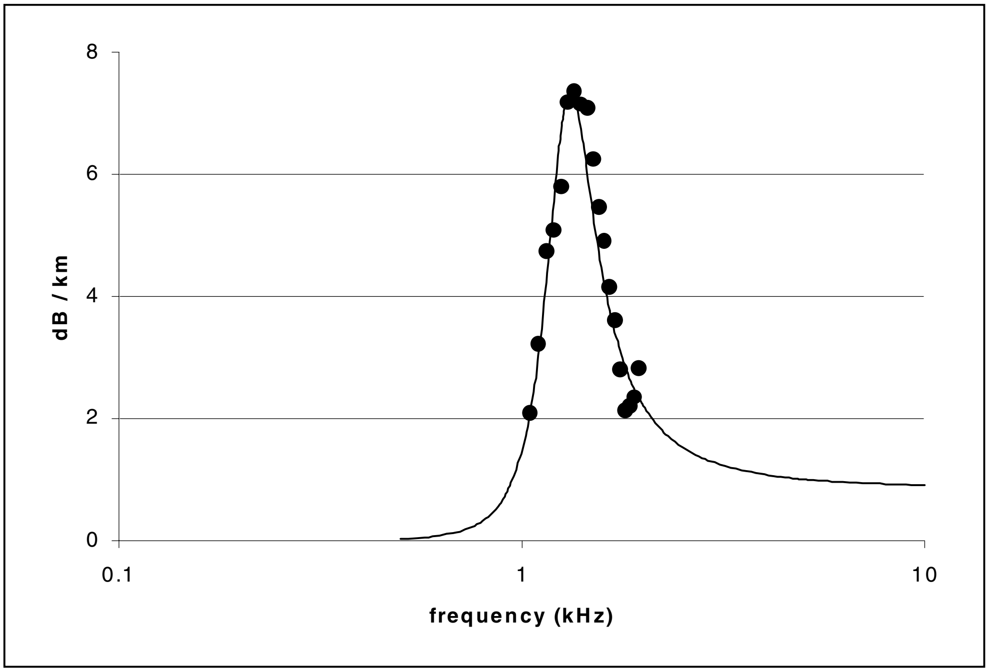
After consideration of all constraints, we agreed that the scientific objectives of this project could be achieved by conducting the proposed experiment in June or July in the Tsushima (Korea) Strait between the East China Sea and the Sea of Japan. If approved, the experiment would be conducted from a SNFRI research vessel. We also agreed that the next round of discussions will be held in the spring of 2001, following the engineering tests of the broadband source, which is expected to occur in January, 2001. If the engineering test (January, 2001) or the first at sea experiment in the seas off California (March, 2001 at the earliest) are delayed, then the planned collaborative experiment with SNFRI, would have to be delayed until June or July, 2002.

I refined my analysis of the causes of the differences between number densities derived from absorptivity and echo sounder data recorded during Model Lion. The resulting paper has been accepted and will be published by the ICES Journal of Marine Science. This paper will be the first to provide a quantitative comparison of number densities derived from absorptivity and echo sounder data.

To permit simulation of the effects of multiple absorption layers with realistic shapes on transmission loss, my colleague, Steve Wales, modified the existing “bioacoustic” C-SNAP transmission loss model, and tested its accuracy. The model was found to be accurate at ranges greater than about 20 water depths (~ 1.2 km in 60 m of water) at frequencies of 1 to 2 kHz.

RESULTS

I reviewed the measurements and times of frequency selective attenuation in the Yellow Sea, which Qui et al. (1999) interpreted in terms of absorptivity due to anchovies. A small percentage of their measurements were made at night (prior to astronomical twilight), when anchovies are dispersed and bioacoustic absorptivity measurements are quantitatively interpretable. I concluded that their interpretation was consistent with previously published bioacoustic parameters of dispersed anchovies.



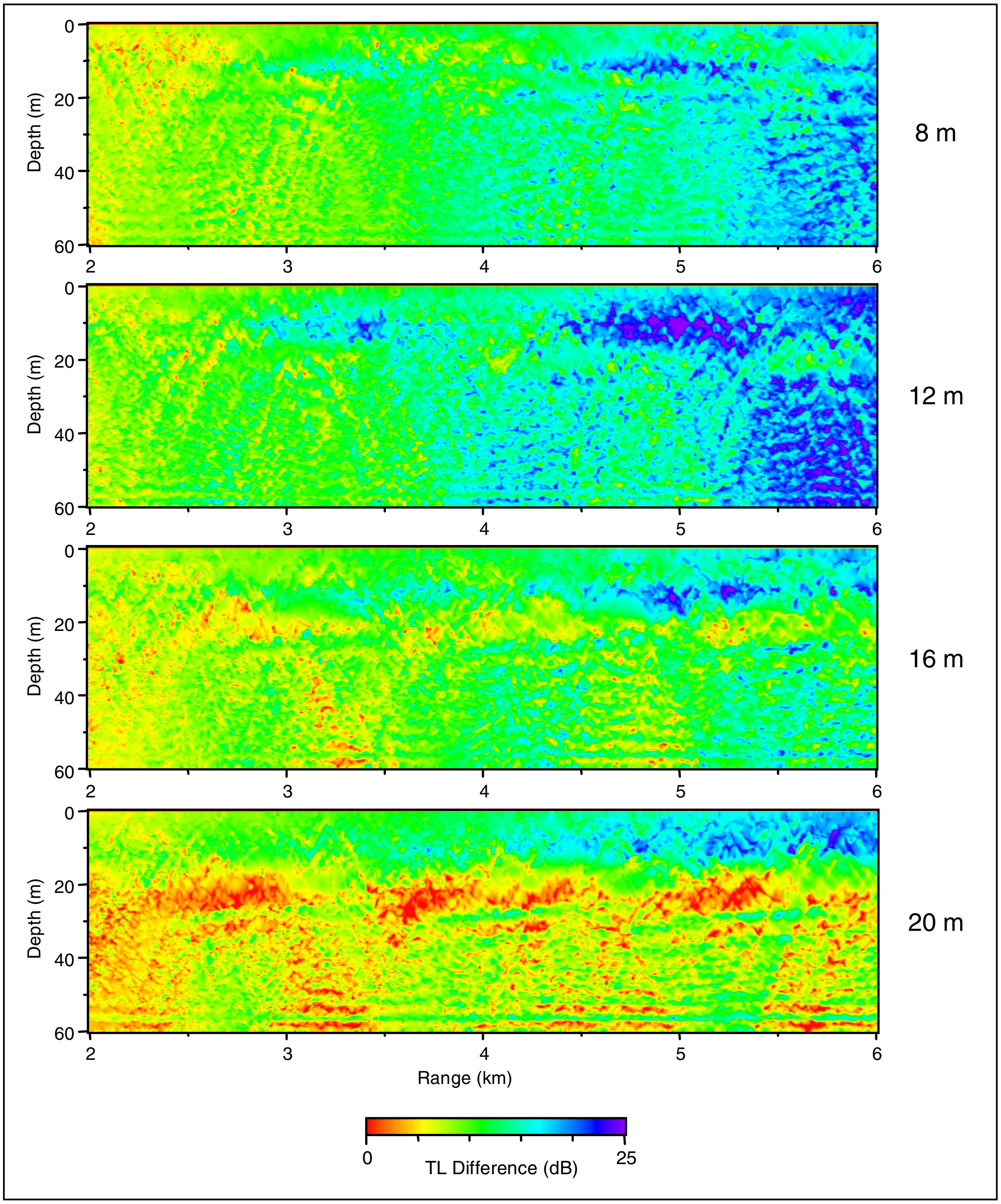
The first figure (above) shows the magnitude of the attenuation coefficient, which was inferred from Qui et al.’s (1999) transmission loss measurements in the Yellow Sea at night, and theoretical calculations of attenuation coefficients as a function of frequency. The experimental values were corrected for bottom attenuation (1 dB / km). The theoretical calculations are based on the equation for the extinction cross section due to an ensemble of identical bubbles with a resonance frequency of 1.32 kHz, and an assumed value of the number of anchovies per m^3. The assumed “ensemble” Q is 2.7, which is reasonable, since the Q_0 of individual anchovies at the depth of the absorption layer (~ 8 meters) is approximately 5. Due to lack of concurrent trawls and echo sounder data, it will not be possible to estimate the magnitude of Q_0 of anchovies from these data. Despite these shortcomings, Qui et al’s (1999) measurements suggest that bioacoustic absorption coefficients in this region are comparable to bioacoustic absorption coefficients at other sites (Ching and Weston, 1971; and Diachok, 1999). Future research on this topic will include simulations of the effects of bioacoustic absorption layers (and boundaries) on the measured depth and frequency dependence of transmission loss in the Yellow Sea.

I demonstrated that previously published measurements of the spectra of back-scattered energy by dispersed anchovies in the Southern California Bight are consistent with a model that accounts for the bioacoustic properties of year classes. Matching of calculations and measurements resulted in estimates of the relative number densities and ensemble Q's of year classes. These inferences of ensemble Q's of year classes influenced the sampling strategy of the ultra broadband source. The results of this work were documented in a paper, which was submitted to the Journal of the Acoustical Society of America (ASA).

I demonstrated that bioacoustic absorption spectra due to dispersed sardines and anchovies in the Gulf of Lion were consistent with a model that accounts for the effects of year classes of these fish. Matching of calculations and measurements resulted in estimates of the number densities and ensemble Q's of year classes. The ensemble Q's of anchovies derived from absorptivity and back-scattering measurements were comparable. Initial results will be presented at the next ASA meeting. Documentation is in progress.

With the assistance of my colleague, Steve Wales, I simulated the effects of bioacoustic absorbing layers on transmission loss from an omni-directional source. Simulations indicated that it will be possible to derive bio-acoustic parameters, including the average length, depth and number densities of fish, using the autonomous broadband source and autonomous broadband receiver. These simulations clearly demonstrated that a densely populated vertical array with a nominal spacing of about 3 meters is required for estimation of depth, whereas estimation of other bioacoustic parameters can be accomplished with a few hydrophones. Based on these simulations, the number of hydrophones in the planned autonomous vertical array was increased from 4 to 16.

The second figure (next page) shows the average difference between transmission loss calculations, which were made at frequencies of 1.3, 1.4, 1.5, 1.6 and 1.7 kHz, with and without a bioacoustic absorbing layer. Selection of these frequencies is consistent with the sampling strategy of the autonomous source, and the nominal value of Q of bioacoustic absorption lines. Calculations are shown as a function of depth and range at source depths of 8, 12, 16 and 20 meters. The bioacoustic absorbing layer is centered at 12 meters and has a half width of 4 meters. The water depth is 60 meters. The sound speed profile has a small negative gradient, and the maximum in the sound speed gradient is at 30 meters. The critical angle in the bottom is 15 degrees, and the attenuation coefficient in the bottom is assumed to be 0.3 dB / λ. These parameters, including the bioacoustic absorption coefficient, were based approximately on environmental parameters, which were measured during Modal Lion (Diachok, 1999).



These calculations suggest that the effects of bioacoustic absorptivity on transmission loss are strongly dependent on source depth, and that excess losses are highest when the source is placed at or near the mid-point of the absorbing layer. The strong source depth dependence in transmission loss is caused by depth dependent differences in modal excitation. When the source is placed at 12 meters, it is possible to determine the mean depth of the absorbing layer at some ranges by inspection. In general, bioacoustic parameters will be estimated through comparisons of measurements and calculations of transmission loss vs. depth and frequency (Diachok, 1999). The range will be selected to maximize the sensitivity to the absorbing layer. Ranges will be kept as short as possible to minimize the need to consider range dependence in sound speed profiles and stochastic mode coupling.

IMPACT / APPLICATIONS

Naval significance: This research suggests that the detection range of naval tactical sonars may be significantly reduced when operating in shallow water environments where large numbers of pelagic fish are present. Strategically important areas where fish concentrations may be particularly high include the shallow seas off the coasts of the United States, Europe and China. The effective Q absorption lines is about 2 or greater. Consequently, combatants with sonars, which operate at different frequencies, could find themselves in situations, where one may have a very long detection range (e.g. at 3 kHz), whereas the other may have a very short detection range (e.g. at 5 kHz), in the same environment, at the same time. Effects due to bioacoustic absorptivity should be incorporated into formulating environmental adaptation strategies for tactical sonars.

Fisheries applications: These results suggest that bioacoustic absorptivity may be used to estimate number density (biomass) of pelagic fish with swim bladders in littoral environments, and to classify fish by length.

TRANSITIONS

Naval Research Laboratory (NRL) has initiated a three year 6.2 research program to conduct experimental and theoretical investigations on the effects of bioacoustic absorptivity on transmission loss in littoral seas. This research program started in FY 00.

RELATED PROJECTS

ONR: Biology Program. NRL: 6.2 research program, “Effects of bioacoustic absorptivity on transmission loss in littoral environments”. Saclant Undersea Research Centre: theoretical modeling. *Discussions in progress*: Sekai National Fisheries Research Institute, Nagasaki, Japan: biological sampling program.

REFERENCES

Holliday, V. “Resonance structure in echoes from schooled pelagic fish”, J. Acoust. Soc. Am., 51, 1322-1332, 1972.

Qui, X. et al., “Frequency selective attenuation of sound propagation and reverberation in shallow water”, J. Sound and Vibration, 1999.

Ching, P. and D. Weston, “Wide band studies of shallow water acoustic attenuation due to fish” J. Sound and Vibration, 18, 499-510, 1971.

PUBLICATIONS

Orest Diachok, “Interpretation of the spectra of energy scattered by dispersed anchovies”, submitted to the Journal of the Acoustical Society of America.

Orest Diachok, “Bioacoustic absorptivity and transmission loss in littoral seas” (Abstract), 139th Meeting of the Acoustical Society of America, 2000.

Orest Diachok, “Comparison of measured and calculated absorption spectra due to ensembles of fish with swim bladders” (Abstract), 140th Meeting of the Acoustical Society of America, 2000.

Paul Smith, Orest Diachok et al., “The potential of bioacoustic absorption spectroscopy measurements for monitoring the growth and mortality rates of juvenile fish with swim bladders” (Abstract), CalCOFI Conference, 2000.

Orest Diachok, “Absorption spectroscopy: a new approach to estimation of biomass”, Fisheries Research, 47, 231-244, 2000; and *Invited talk*, presented at the 1997 Meeting of the American Fisheries Society.

Orest Diachok, Bernard Liorzou and Carla Scalabrin, “Estimation of the number density of fish from resonance absorptivity and echo sounder data”, ICES Journal of Marine Science, 2000 (in press).

Orest Diachok, “Effects of absorptivity due to fish on transmission loss in shallow water”, Journal of the Acoustical Society of America, 105, 2107-2128, 1999.

Orest Diachok, “Bioacoustic resonance absorption spectroscopy”, *Invited paper*, Special Session on Acoustics of Fish, Fisheries and Plankton, Proceedings of the ICA / ASA Meeting in Seattle, 1998.

Orest Diachok and Paul Smith, “Monitoring the growth and mortality rates of pelagic fish with absorption spectroscopy measurements”, Special Session on Acoustics of Fish Fisheries and Plankton, Proceedings of the ICA / ASA Meeting in Seattle, 1998.

Orest Diachok, “Bioacoustic absorption spectroscopy”, 1998 NRL Review, Naval Research Laboratory, Washington, D.C., 85-87, 1998.

Orest Diachok and Carlo Ferla, “Measurement and simulation of the effects of absorptivity due to fish on transmission loss in shallow water”, Proceedings of the Oceans 96 Conference, IEEE Press, 1996.

PATENTS

The Naval Research Laboratory has applied for an international patent on my design of low cost, large bandwidth, light weight, autonomous source and receiver arrays. These systems are specifically designed to permit bioacoustic absorption spectroscopy measurements to be made between a fixed broadband source and multiple, widely spaced fixed receiving arrays in littoral seas.